United States Patent [19]

Webster

[11] **4,391,514**

[45] **Jul. 5, 1983**

[54] **SIDELOOKING LASER ALTIMETER FOR A FLIGHT SIMULATOR**

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[73] Assignee: **The United States of America as represented by the Administrator of the National Aeronautics and Space Administration,** Washington, D.C.

[21] Appl. No.: **234,224**

[22] Filed: **Feb. 13, 1981**

[51] **Int. Cl.**³ **G01C 3/10;** G09B 9/08

[52] **U.S. Cl.** **356/1;** 356/4; 358/104; 358/109; 434/4; 434/38

[58] **Field of Search** 434/4, 38; 356/1, 4; 358/109, 104

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,183,295	5/1965	Myles	434/4
3,194,869	7/1965	Eisenberg	434/4
4,068,955	1/1978	Bodlaj	356/1
4,097,154	6/1978	Peters et al.	434/43
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FOREIGN PATENT DOCUMENTS

WO80/02455	11/1980	PCT Int'l Appl.	356/1

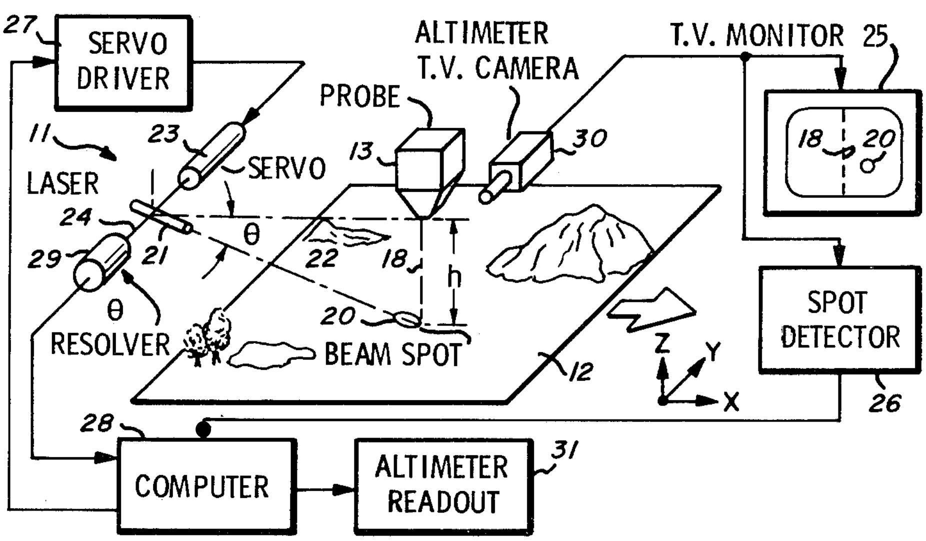
Primary Examiner—S. C. Buczinski
Attorney, Agent, or Firm—Darrell G. Brekke; John R. Manning; Robert D. Marchant

[57] **ABSTRACT**

The object of the invention is to provide an improved laser altimeter for a flight simulator which will allow measurement of the height of the simulator probe above the terrain directly below the probe tip.

A laser beam **22** is directed from the probe **13** at an angle θ to the horizontal to produce a beam spot **20** on the terrain. The angle θ that the laser beam **22** makes with the horizontal is varied so as to bring the beam spot into coincidence with a plumb line **18** coaxial with the longitudinal axis of the probe **13**. A television altimeter camera **30** observes the beam spot and has a raster line aligned with the plumb line **18**. Spot detector circuit **26** coupled to the output of the TV camera monitors the position of the beam spot relative to the plumb line **18**. An error signal is produced by computer **28** driving, via a servo motor **23**, the laser beam optics so as to cause the beam spot to come into coincidence with the plumb line **18**. At coincidence, computer **28** looks up in a table the altitude of the probe for the given angle θ and reads out the altitude to an altimeter readout **31**.

11 Claims, 9 Drawing Figures



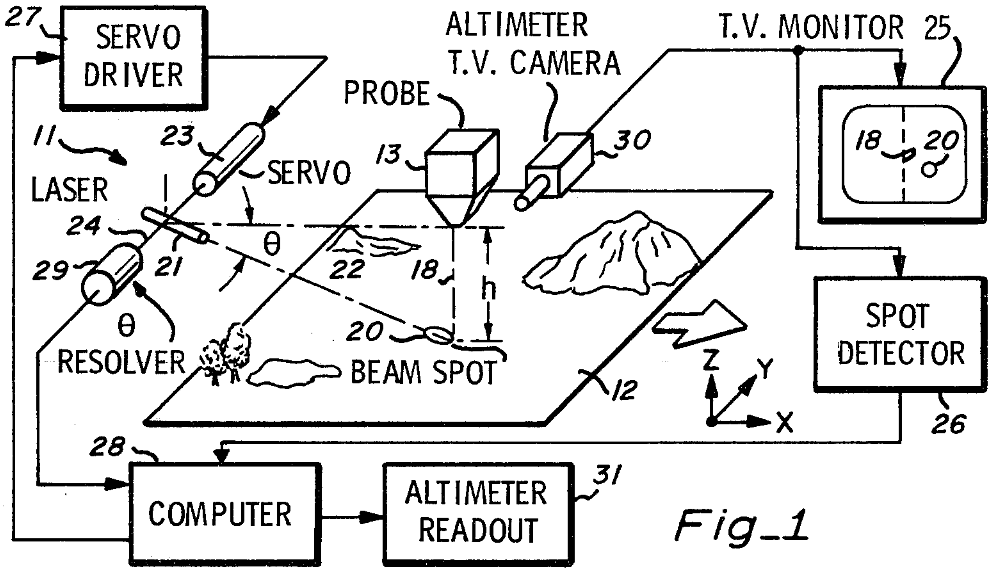


Fig_1

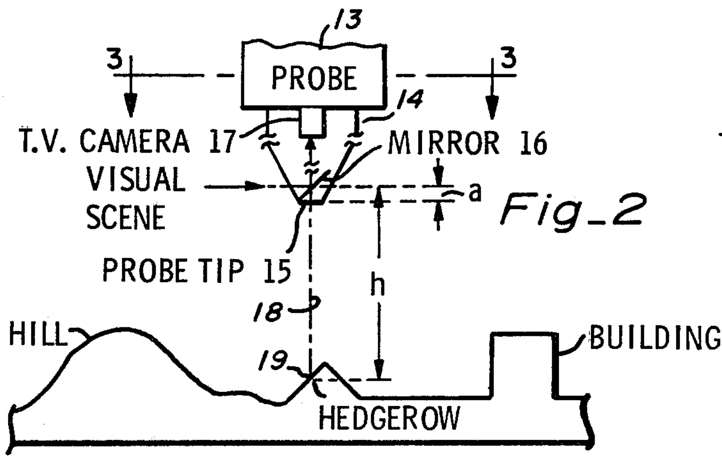


Fig_2

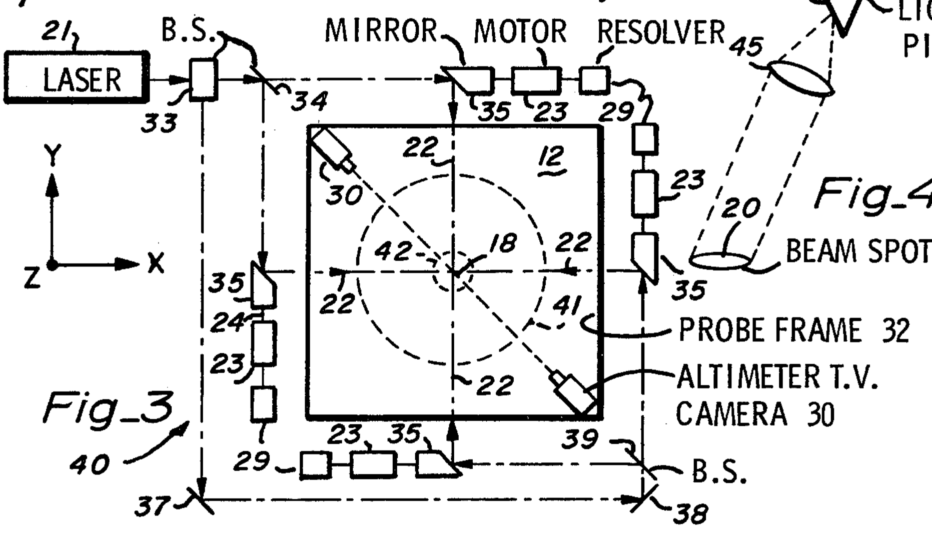


Fig_3

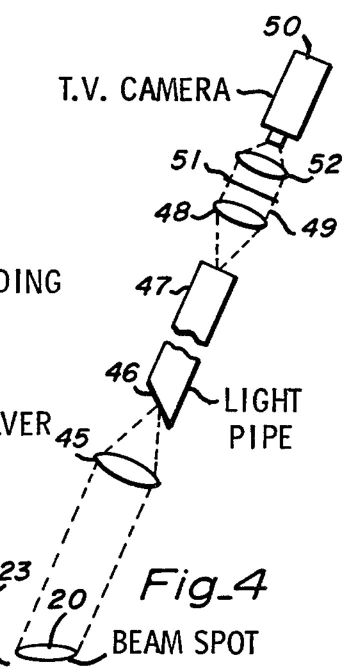


Fig_4

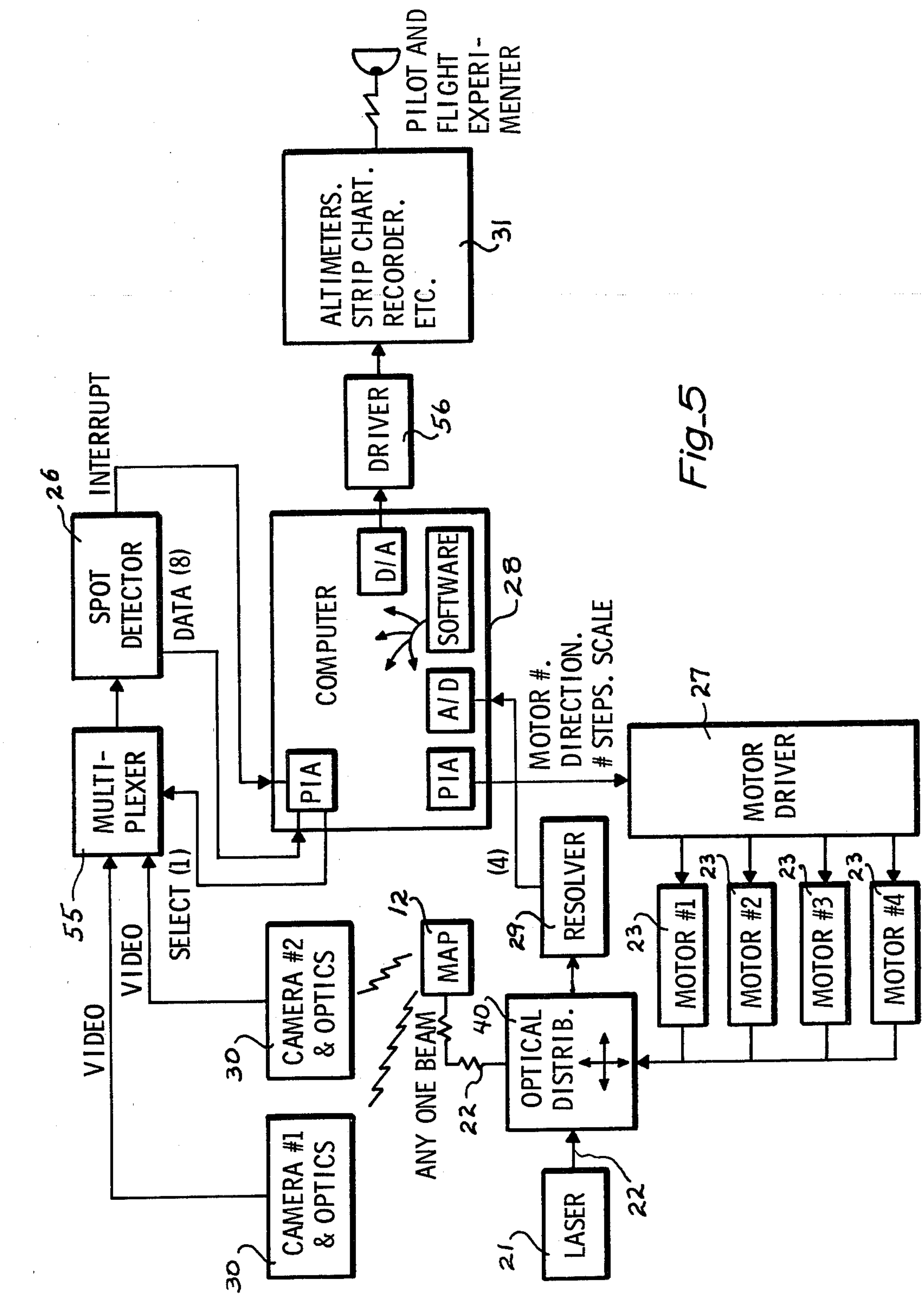

PILOT AND FLIGHT EXPERI-MENTER
ALTIMETERS. STRIP CHART. RECORDER. ETC.
31
DRIVER
56
INTERRUPT
26
SPOT DETECTOR
DATA (8)
COMPUTER
D/A
SOFTWARE
28
A/D
PIA
PIA
MOTOR #. DIRECTION. # STEPS. SCALE
27
MOTOR DRIVER
MULTI-PLEXER
55
VIDEO
VIDEO
SELECT (1)
(4)
RESOLVER
29
12
MAP
CAMERA #2 & OPTICS
30
CAMERA #1 & OPTICS
30
ANY ONE BEAM
40
22
OPTICAL DISTRIB.
LASER
21
22
23
MOTOR #1
MOTOR #2
MOTOR #3
MOTOR #4

Fig_5

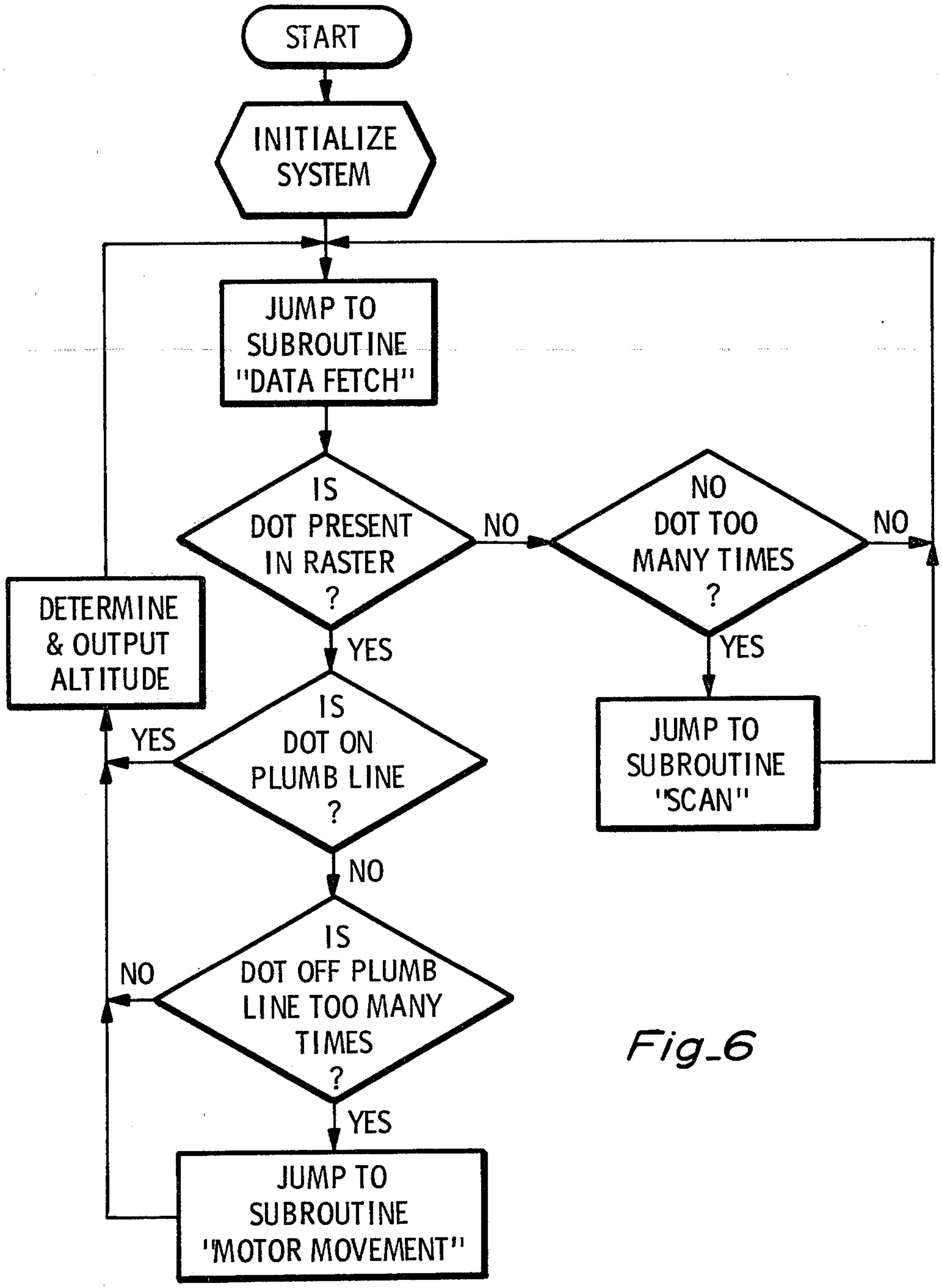

START
INITIALIZE SYSTEM
JUMP TO SUBROUTINE "DATA FETCH"
IS DOT PRESENT IN RASTER ?
NO
NO DOT TOO MANY TIMES ?
NO
YES
JUMP TO SUBROUTINE 'SCAN"
YES
IS DOT ON PLUMB LINE ?
YES
DETERMINE & OUTPUT ALTITUDE
NO
IS DOT OFF PLUMB LINE TOO MANY TIMES ?
NO
YES
JUMP TO SUBROUTINE 'MOTOR MOVEMENT"

Fig_6

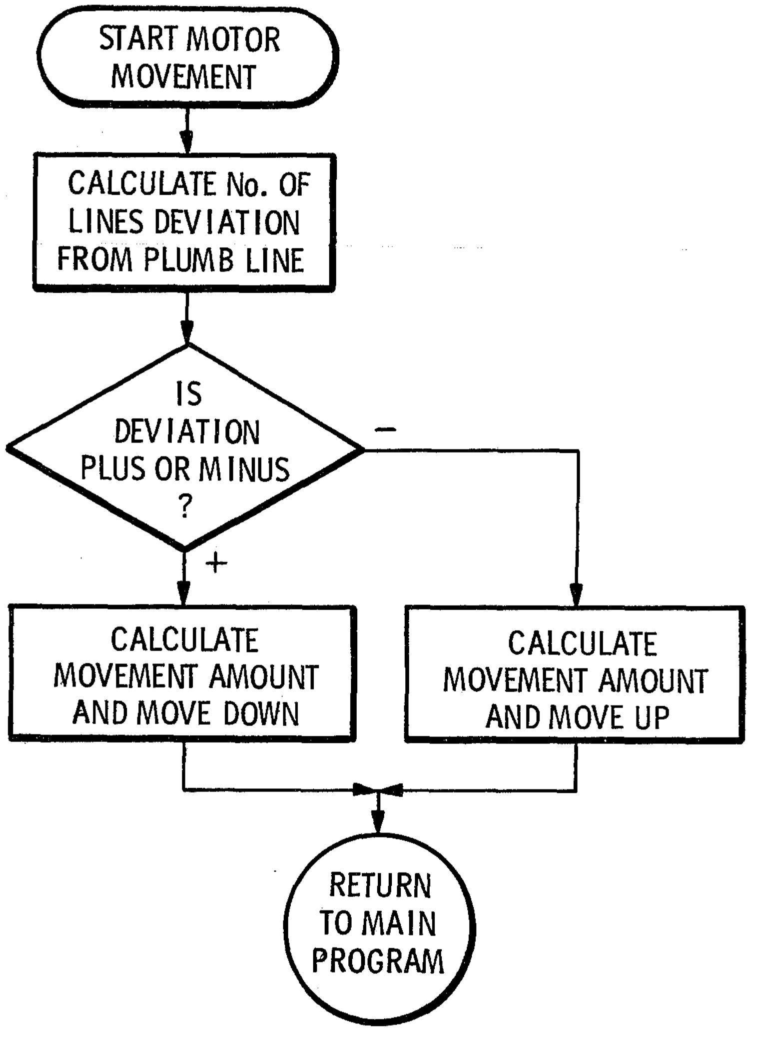

START MOTOR MOVEMENT
CALCULATE No. OF LINES DEVIATION FROM PLUMB LINE
IS DEVIATION PLUS OR MINUS ?
−
+
CALCULATE MOVEMENT AMOUNT AND MOVE DOWN
CALCULATE MOVEMENT AMOUNT AND MOVE UP
RETURN TO MAIN PROGRAM

Fig_7

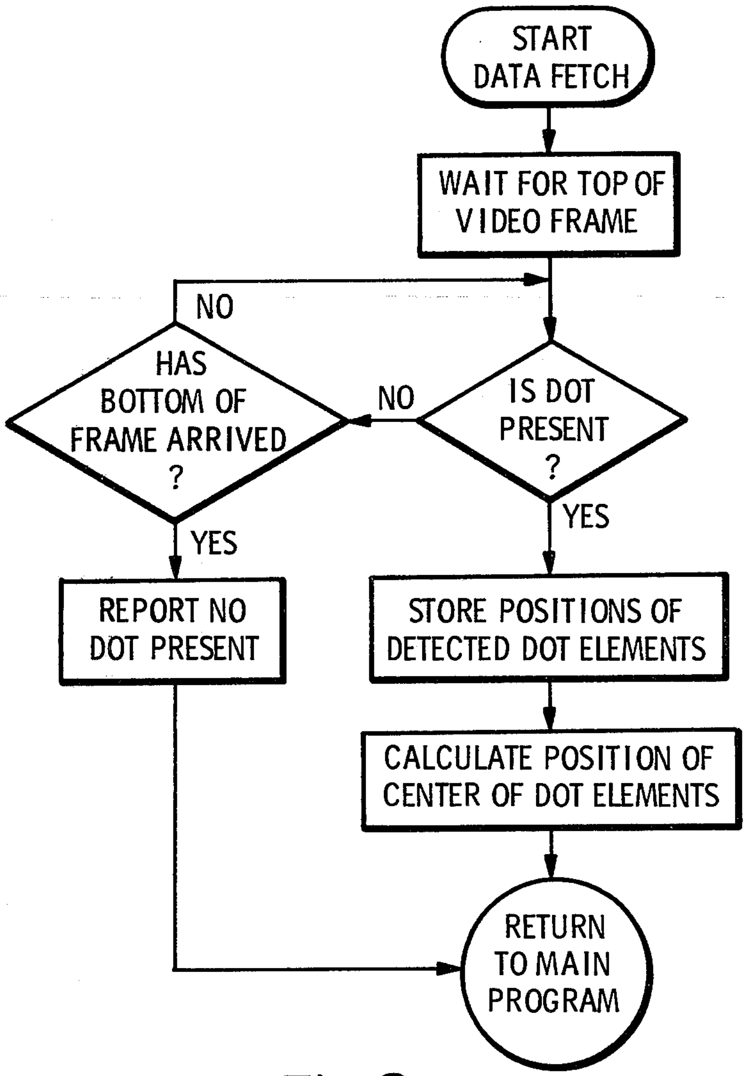

START
DATA FETCH
WAIT FOR TOP OF
VIDEO FRAME
NO
HAS
BOTTOM OF
FRAME ARRIVED
?
NO
IS DOT
PRESENT
?
YES
YES
REPORT NO
DOT PRESENT
STORE POSITIONS OF
DETECTED DOT ELEMENTS
CALCULATE POSITION OF
CENTER OF DOT ELEMENTS
RETURN
TO MAIN
PROGRAM

Fig_8

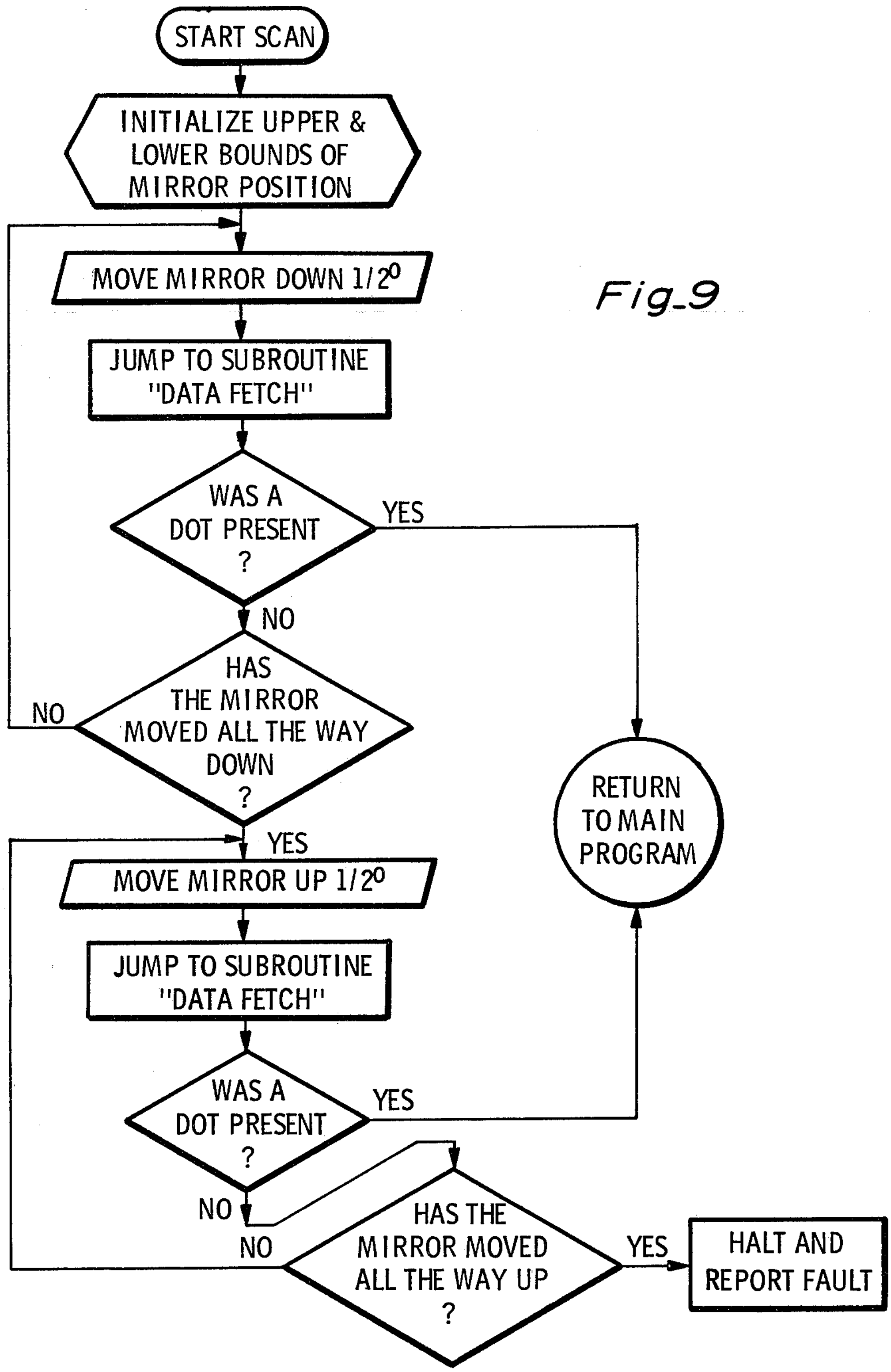

START SCAN
INITIALIZE UPPER & LOWER BOUNDS OF MIRROR POSITION
MOVE MIRROR DOWN 1/2°
JUMP TO SUBROUTINE "DATA FETCH"
WAS A DOT PRESENT ?
YES
NO
HAS THE MIRROR MOVED ALL THE WAY DOWN ?
NO
YES
RETURN TO MAIN PROGRAM
MOVE MIRROR UP 1/2°
JUMP TO SUBROUTINE "DATA FETCH"
WAS A DOT PRESENT ?
YES
NO
NO
HAS THE MIRROR MOVED ALL THE WAY UP ?
YES
HALT AND REPORT FAULT

Fig_9

SIDELOOKING LASER ALTIMETER FOR A FLIGHT SIMULATOR

ORIGIN OF THE INVENTION

The invention described herein was made by an employee of the U.S. Government and may be manufactured and used by or for the Government for Governmental purposes without the payment of any royalties thereon or therefor.

TECHNICAL FIELD

The technical field of the present invention relates in general to laser altimeters for flight simulators.

BACKGROUND ART

Heretofore a laser altimeter system has been proposed for determining the altitude of a flight simulation probe over a model board. Such a prior art system is disclosed in an article entitled, "Probe Protection In Camera/Model Visual Systems" appearing in the Proceedings of the 1980 Summer Computer Simulation Conference, Olympic Hotel, Seattle, Wash., Aug. 25–27, 1980.

In this system, a laser beam is directed vertically from the flight simulator TV camera probe along a side of the probe to strike a point on the model board radially displaced from a point directly below the center line of the probe, hereafter referred to as a plumb line. The incident beam produces a beam spot on the terrain of the model which is thence imaged onto a linear array sensor. As the height of the probe is varied, while holding the probe otherwise stationary, from a point of minimum altitude to a point of maximum altitude the beam spot traverses a vertical imaginary line focused onto the linear array sensor. The position of the imaged beam spot along the linear array sensor is representative of altitude. A major problem with this system is that the altitude being measured is not the altitude of the probe (altitude measured along the plumb line) but rather the altitude of the laser beam source which is displaced horizontally from the probe. The actual distance between the plumb line and the laser beam must be multiplied by the scale of the model. Error will be produced whenever the terrain elevation at the plumb line differs from the terrain elevation at the laser beam. For example, an appreciable error would exist if the plumb line was over a depression and the laser beam impinged on a hill, mountain or tall building.

Thus, it is desirable to obtain a probe height sensor which more accurately measures the height of the probe above the terrain directly below the probe.

[STATEMENT OF INVENTION]

DISCLOSURE OF INVENTION

In the present invention, pilot altitude as represented by the distance h is measured by a technique that locates the point of intersection of the plumb line and the terrain (hereinafter known as the convergence point). A laser beam is directed from the probe at an angle to the plumb line and coaxial with the longitudinal axis of the probe. The point where the beam strikes the terrain is varied by changing the angle of the laser beam relative to the longitudinal axis of the probe so that the beam spot is brought to a point on the longitudinal axis of the probe where it intersects the terrain. A TV camera, carried from the probe views the region below the probe and has a predetermined linear detection region,

such as a raster line, coaxially aligned with the image of the plumb line. A detection circuit receives the output of the TV camera and determines the position of the laser dot in the raster. Using this information, a computer determines the position of the beam spot relative to the plumb line. A resolver coupled to the laser beam angle control reads out the angular position θ of the laser beam to a computer. The computer looks up the height of the probe in a look up table for the angle θ of the laser beam. The measured height is then read out to an altimeter and to a flight simulation monitor station. If the laser dot does not reside on the plumb line, a computer directs a stepper motor to relocate the beam such that the dot will reside on the plumb line. If the operative laser beam is unable to be relocated at the convergence point because it is blocked by a terrain obstruction, an alternative laser beam at a different angle around the probe is selected. Also, if the TV camera's view is blocked the computer selects an alternative TV camera.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a schematic perspective view, partly in block diagram form, of an altimeter system for a flight simulator incorporating features of the present invention,

FIG. **2** is a longitudinal sectional view of the flight simulator probe and model board,

FIG. **3** is a schematic transverse sectional view, partly in block diagram form, of a portion of the structure of FIG. **2** taken along line **3—3** in the direction of the arrows,

FIG. **4** is a schematic side elevational view of the TV camera optics for beam spot detection,

FIG. **5** is a schematic block diagram of a laser altimeter system incorporating features of the present invention,

FIG. **6** is a logic flow diagram for the computer program for the system of the present invention, and

FIGS. **7**, **8**, and **9** are logic flow diagrams for subroutines of the computer program flow diagram depicted in FIG. **6**.

DETAILED DESCRIPTION OF THE INVENTION

Referring now to FIG. **1** there is shown a laser altimeter system **11** for a flight simulator and incorporating features of the present invention. The flight simulator system includes a model board **12** comprising a scale model of terrain over which simulated flights are to be conducted. The pilot sits in a cockpit, not shown, and views a television screen displaying a view seen through a probe **13** movable with respect to the terrain of the model board **12** in accordance with flight control commands given by the pilot over the aircraft controls. The probe **13** is carried from a gantry, not shown, disposed over the terrain of the model board **12**. Relative movement in three orthogonal directions, X, Y, and Z is obtained between the probe and the model board. In some embodiments, the gantry moves relative to a stationary model board to provide movement in all three orthogonal directions, whereas, in other embodiments the model board is moved relative to the probe to simulate flight.

Referring now to FIG. **2**, the optical system for the probe **13** is shown in greater detail. More particularly, the probe **13** includes an elongated barrel portion **14**

projecting in the Z direction toward the model board. At the end or tip of the probe **15** there is a mirror **16** which projects a visual scene corresponding to that which would be seen by the pilot, up along the longitudinal axis of the probe barrel **14** to a TV camera **17**. The scene picked up by the TV camera is then transmitted to and displayed on a cathode ray tube outside the windshield of the simulated aircraft. The altitude h of the simulated aircraft is that scale distance from the mirror **16** is taken along a plumb line **18** for the modeled terrain to a point of intersection of the plumb line with the terrain at **19**.

Referring again to FIG. **1**, a laser **21** is carried from a frame coupled to and movable with the probe **13**. The laser directs a pencil-like beam **22** of monochromatic nondivergent radiation of visible wavelength onto the terrain below the probe **13** having been deflected by pitchable mirror **35** to produce a beam spot **20** on the terrain. A servo motor **23** is coupled to the mirror **35** in such a way as to vary the angle θ that the laser beam makes to the horizontal or XY plane of the model board **12**. The laser beam is rotatable about an axis of revolution parallel to the horizontal XY plane and such beam being rotatable in a plane normal to said axis of revolution, such plane also containing the plumb line **18**.

An altimeter TV camera optical system **30** is also carried from the probe frame. The altimeter TV camera system **30** includes some optics, not shown, and views the region of the model board directly below the probe **13**. The TV camera optics are such that the point of intersection of plumb line **18** with the model board surface is within the view of the TV camera system **30** for all values of altitude h from minimum to maximum above the surface of the model board **12**.

A single raster line is made coincident with the plumb line **18** through appropriate mechanical alignment. An output from the altimeter TV camera **30** goes to a spot detector circuit **26** of the type similar to that disclosed in U.S. Pat. No. 3,320,360 issued May 16, 1967 entitled, "Television Tracking Error Detector", for determination of the location of the beam spot **20** relative to the plumb line **18**.

The output of spot detector **26** is fed to a computer **28**. This output consists of the raster line number and displacement along the raster line of all of the detected elements of the laser spot **20**. The computer determines the location of the center of the laser spot **20** in the raster of the altimeter TV camera system **30**. To be coincident with the end of the plumb line **18**, the laser spot **20** must lie somewhere along the altimeter TV camera system raster line which was made coincident with the plumb line **18**. The computer **28** compares the raster line number of the center of the laser spot **20** with the raster line number of the raster line which is coincident with the plumb line **18**. If the two are equal then the laser spot **20** must be located on the terrain at the end of plumb line **18** where it intersects the terrain. The exact length of plumb line **18** may then be determined. If the two are not equal, the laser spot **20** is not located at the end of plumb line **18** where it intersects the terrain. An error signal is generated which causes servo driver **27** to reposition laser spot **20** until the two raster line numbers are equal. The computer **28** also receives the angle θ input from a resolver **29** mechanically coupled to the laser beam deflection system so that at the point of convergence of the beam spot **20** with the point of entry of the plumb line **18** into the terrain, the computer reads the θ angle and looks up, in its look up table, the value of altitude corresponding to the given values of altitude for various values of θ as the probe is moved from a position of minimum altitude to maximum altitude over the model board.

Referring now to FIG. **3** there is shown the optical distribution system for deriving the various laser beams and for televising the beam spot **20** on the model board. The laser **21** is affixed to a probe frame member **32**, and directs its output beam through first and second beam splitters **33** and **34**. Beam splitter **33** is arranged to direct the reflected portion of the beam downward along the Z axis whereas the other half of the beam passes through the first beam splitter **33**, to the second beam splitter **34** which serves to further divide the beam into a first beam directed parallel to the X axis and a second beam of equal amplitude directed along the Y axis. Each of the beams outputted from the second beam splitter **34** is directed onto a 45° angle mirror **35** for bending the respective beam by 90° toward the plumb line **18**. Each of the mirrors is driven from a stepping servo motor **23** about respective axes of revolution. In one instance the axis of revolution is parallel to the X axis and in the other to the Y axis and both are in the XY plane so as to cause the beams to be rotated within respective planes which are perpendicular to the XY plane and each of which includes the plumb line **18**. A θ angle resolver **29** is coupled to each of the motor-mirror drive trains for giving an output determinative of the angle θ.

The other half of the output of the first beam splitting mirror **33** is directed downward along the Z axis to a 45° mirror, not shown, which thence directs the beam parallel to the Y axis to a second 45° mirror **37** and thence parallel to the X axis to another 45° mirror **38** which thence directs the beam through a second beam splitting mirror **39** for splitting the beam into two equal components, one parallel to the Y axis and the other parallel to the X axis. The beams are then reflected off of respective 45° mirrors **35** driven from the stepping motors **23** which include resolvers **29**. Thus, the second beam produces a pair of beams directed onto the model board **12** which are orthogonal to each other and which are 180° displaced from the first pair of beams. The beams are rotatable in the XZ and YZ planes, such planes each including the plumb line **18**. The respective mirrors **35** are positioned such that their output beams will intersect the plumb line **18** at the point that the plumb line **18** intersects the surface of the model **12**.

The orthogonality between each of the laser beams is not a requirement. For example, it could be three beams at 120° angular spacing from each other with the camera optics similarly angularly separated from each other by 120° and being spaced at 60° angles from each of the respective beams.

A pair of altimeter TV camera optics are carried from the probe frame structure **32** and are positioned at 180° intervals about an axis of revolution coaxial with the plumb line **18** and preferably at 45° angular spacing from the ZX or ZY planes but on the XY plane containing the respective laser beams. This positioning of the altimeter TV camera optics **30** permits viewing of the respective beam spot **20** at the plumb line **18**, regardless of various buildings, hills, or trees or other obstructions in the terrain of the model board **12**. In other words there is some combination of laser beam **22** and altimeter TV camera optics **30** which will permit viewing of the beam spot **20** at the plumb line **18** regardless of the obstructions represented by the terrain of the model **12**, with the exception of a well or deep ravine. The laser

beams **22** which are not in use, i.e., three of the four are "parked" by rotating their respective mirrors **35** so as to project the beam spot **20** onto the probe body **41** or **42**.

Referring now to FIG. **4** there is shown one of the optical systems **30** for each of the TV altimeter cameras. More particularly, a condensing lens **45** receives the light emanating from the beam spot **20** and focuses the image of the beam spot onto the entrance plane **46** of a light pipe **47** such as a fiber optics bundle. The bundle **47** may have a suitable length as of 3–5 feet to bring the image of the beam spot **20** to a convenient location of the TV camera **50**, typically somewhere on the gantry. Another lens **48** receives the beam spot image at the output face of the light pipe **47** and converts the image into a beam of parallel light **49** which is thence directed through a narrow pass filter **51** having a pass band at the wavelength of the laser beam **22** so as to filter out undesired background illumination. The filtered beam is thence fed to a condensing lens **52** which focuses the beam spot image onto the receiving face of the TV camera **50**. The input face of the light pipe **46** is cut at the Scheimpflug angle, as described in U.S. Pat. No. 751,347 issued Feb. 2, 1904, so that the plumb line **18** of the probe is maintained in focus on the input face of the TV camera **50**.

Referring now to FIG. **5** there is shown, in block diagram form, the laser altimeter system **11** of the present invention. The output beam **22** of the laser **21** is fed through an optical distribution system **40** as shown in FIG. **3**. One of the output beams **22** is selected and directed onto the terrain of the model **12** under the probe **14**. The beam spot image **20** is picked up by both of the camera optical systems **30**. Their output video signals are fed to a multiplexer **55**. The computer **28** selects one or the other of the camera optic systems **30** and feeds a control signal to the multiplexer **55** for controlling which one of the camera optic systems **30** is utilized. The output of the multiplexer **55** is fed to the spot detector **26** which tracks the image of the beam spot **20** relative to the plumb line **18** which is inputted to the computer **28** and thence outputted to the motor driver **27** and respective motor **23**. In a typical example, the computer **28** comprises a Motorola 6800 Exorcisor. The resolver **29** outputs the angle θ for the selected beam **22** to an analog-to-digital converter in the computer **28**. When the computer **28** detects zero error, i.e., the beam spot is at the plumb line **18**, the computer **28** by its software looks up in a table the altitude corresponding to the respective angle θ and outputs that data via a digital-to-analog converter to a driver **56** which thence inputs it to the altimeters or other read out devices **31**.

Referring now to FIG. **6**, there is shown the logic flow chart for the software program for the computer **28**. FIGS. **7–9** depict the logic flow charts for program subroutines, namely, MOTOR MOVEMENT, DATA FETCH, and SCAN, respectively. The program listing is shown in Appendix I, below.

One of the advantages of the laser altimeter system of the present invention for a flight simulator includes detecting the altitude of the probe above a position directly below the probe as opposed to a position displaced in the horizontal plane from the probe. This makes the concept inherently accurate. Secondly, the provision of angularly displaced laser beams **22** and camera optics **30** allows reading of the altitude regardless of the obstructions represented by features in the terrain which might otherwise obstruct viewing of the beam spot.

APPENDIX I

```
00010 00001                                   *****************************************
00020 00002                                   *                 LASER                 *
00030 00003                                   *               OPERATING               *
00040 00004                                   *                SYSTEM                 *
00050 00005                                   *****************************************
00060 00006                                      NAM     LASOP
00070 00007A 5000                                ORG     $5000
00080 00008                                      OPT     CRE,L,P=43,U,LLE=90
00090 00009A 5000       019F   A CONV            FDB     $019F      CONVERGENT RASTER LINE
00100 00010A 5002       04     A SMMV            FCB     $4         SMALL MVT THRESHOLD
00110 00011A 5003       08     A MDMV            FCB     $8         MEDIUM MVT THRESHOLD
00120 00012A 5004       10     A LGMV            FCB     $10        LARGE MVT THRESHOLD
00130 00013A 5005       03CF   A BIAS            FDB     $03CF      BIAS FOR ALTIM. ZERO
00140 00014A 5007 7F    EF41   A                 CLR     $EF41      SET UP COLECT PIA'S
00150 00015A 500A 7F    EF43   A                 CLR     $EF43
00160 00016A 500D 7F    EF51   A                 CLR     $EF51
00170 00017A 5010 7F    EF53   A                 CLR     $EF53
00180 00018A 5013 7F    EF40   A                 CLR     $EF40
00190 00019A 5016 7F    EF42   A                 CLR     $EF42
00200 00020A 5019 7F    EF50   A                 CLR     $EF50
00210 00021A 501C 86    9C     A                 LDAA    #$9C
00220 00022A 501E B7    EF52   A                 STAA    $EF52
00230 00023A 5021 86    04     A                 LDAA    #4
00240 00024A 5023 B7    EF53   A                 STAA    $EF53
00250 00025A 5026 B7    EF43   A                 STAA    $EF43
00260 00026A 5029 7F    EF52   A                 CLR     $EF52      STOP HARDWARE SYSTEM
00270 00027A 502C 86    06     A                 LDAA    #6
00280 00028A 502E B7    EF41   A                 STAA    $EF41
00290 00029A 5031 B7    EF51   A                 STAA    $EF51
00300 00030A 5034 B6    EF50   A                 LDAA    $EF50      CLR INTERRUPT
00310 00031A 5037 B6    EF52   A FLAG            LDAA    $EF52      INITIALIZE EVENT COUNTER
00320 00032A 503A 84    20     A                 ANDA    #$20
00330 00033A 503C 27    0A 5048                  BEQ     OUTLOP     BUFFER EMPTY?
00340 00034A 503E 86    10     A                 LDAA    #$10       RAISE READ ENABLE
00350 00035A 5040 B7    EF52   A                 STAA    $EF52
```

```
00036A 5043 7F EF52  A          CLR    $EF52
00037A 5046 20 EF 5037          BRA    FLAG      RETURN, INITIAL DONE?
00038A 5048 7F 533A  A OUTLOP   CLR    STABLE    LINE STABILITY CHECK
00039A 504B 7F 5339  A          CLR    STB1      # OF NO DOT PASSES
00040A 504E 7F EF71  A          CLR    $EF71     INITIALIZE MOTOR PIA
00041A 5051 86 FF    A          LDAA   #$FF
00042A 5053 B7 EF70  A          STAA   $EF70
00043A 5056 86 06    A          LDAA   #6
00044A 5058 B7 EF71  A          STAA   $EF71
00045A 505B BD 50A2  A GO       JSR    COLECT    GO GET DATA FROM VIDEO
00046A 505E BD 525A  A          JSR    DIST      GO CALC ALTITUDE
00047A 5061 FE 53D6  A          LDX    DOT
00048A 5064 27 0A 5070          BEQ    STA1      IS DOT (NOT) THERE?
00049A 5066 7F 5339  A          CLR    STB1      IF DOT, CLR # NO DOTS
00050A 5069 8C 0001  A FILTER   CPX    #1
00051A 506C 27 ED 505B          BEQ    GO        SYSTEM ERROR, TRY AGAIN
00052A 506E 20 14 5084          BRA    RUN       RUN SYSTEM WITH GOOD DOT
00053A 5070 86 01    A STA1     LDAA   #1        # OF CONSEQ. NO DOT PASS
00054A 5072 B0 5339  A          SUBA   STB1
00055A 5075 27 05 507C          BEQ    SEND      NO DOT TWICE?
00056A 5077 7C 5339  A          INC    STB1      ACK ONE NO DOT PASS
00057A 507A 20 DF 505B          BRA    GO
00058A 507C 7F 5339  A SEND     CLR    STB1      CLR # OF NO DOT PASSES
00059A 507F BD 5179  A          JSR    HUNT      GO HUNT FOR MISSING DOT
00060A 5082 20 D7 505B          BRA    GO        RETURN AND TRY AGAIN
00061A 5084 BC 5000  A RUN      CPX    CONV      RASTER LINE STAB. TEST
00062A 5087 27 0C 5095          BEQ    SET1      CONVERGENT?
00063A 5089 86 01    A          LDAA   #1        PUT STABLE BIT HERE
00064A 508B B0 533A  A          SUBA   STABLE
00065A 508E 27 0D 509D          BEQ    DRIVE     IS DOT NOT CONV?
00066A 5090 7C 533A  A          INC    STABLE    ACK NOT CONV PASS
00067A 5093 20 C6 505B          BRA    GO        RETURN AND TRY AGAIN
00068A 5095 7F 533A  A SET1     CLR    STABLE
00069A 5098 BD 525A  A          JSR    DIST      CALC DIST FOR ALTIM
00070A 509B 20 BE 505B          BRA    GO        RETURN AND PROCESS AGAIN
00071A 509D BD 5200  A DRIVE    JSR    MOVE      GO TO MIRROR ADJUST SR.
00072A 50A0 20 B9 505B          BRA    GO        RETURN AND REPROCESS
00073A 50A2 7F 5359  A COLECT   CLR    LDATA     INITIALIZE DATA REG'S
00074A 50A5 7F 535A  A          CLR    LDATA+1
00075A 50A8 7F 5395  A          CLR    DDATA
00076A 50AB 7F 5396  A          CLR    DDATA+1
00077A 50AE 7F 53D1  A          CLR    COUNT1
00078A 50B1 7F 53D2  A          CLR    NUMB1
00079A 50B4 7F 53D5  A          CLR    COUNT2
00080A 50B7 B6 EF50  A          LDAA   $EF50     CLR H-WARE INTERRUPT
00081A 50BA 86 80    A          LDAA   #$80
00082A 50BC B7 EF52  A          STAA   $EF52     START HARDWARE RUNNING
00083A 50BF 86 FF    A          LDAA   #$FF      LOOP TIMER
00084A 50C1 F6 EF51  A JMP2     LDAB   $EF51     CHECK FOR DOT INTERRUPT
00085A 50C4 2B 39 50FF          BMI    READ      IF SEE DOT, READ DATA
00086A 50C6 FF 53D3  A          STX    DUMMY     PAD LOOP TIME
00087A 50C9 FF 53D3  A          STX    DUMMY
00088A 50CC FF 53D3  A          STX    DUMMY
00089A 50CF FF 53D3  A          STX    DUMMY
00090A 50D2 FF 53D3  A          STX    DUMMY
00091A 50D5 FF 53D3  A          STX    DUMMY
00092A 50D8 FF 53D3  A          STX    DUMMY
00093A 50DB FF 53D3  A          STX    DUMMY
00094A 50DE FF 53D3  A          STX    DUMMY
00095A 50E1 FF 53D3  A          STX    DUMMY
00096A 50E4 FF 53D3  A          STX    DUMMY
00097A 50E7 FF 53D3  A          STX    DUMMY
00098A 50EA FF 53D3  A          STX    DUMMY
00099A 50ED FF 53D3  A          STX    DUMMY
00100A 50F0 7C 53D1  A          INC    COUNT1    # OF NO DOT LOOPS
00101A 50F3 B1 53D1  A          CMPA   COUNT1    $FF LOOPS?
00102A 50F6 26 C9 50C1          BNE    JMP2      RETURN AND TRY AGAIN
00103A 50F8 CE 0000  A          LDX    #0
00104A 50FB FF 53D6  A          STX    DOT       NO DOT FOUND
00105A 50FE 39                  RTS              RETURN TO MAIN PROG
00106A 50FF 7F EF52  A READ     CLR    $EF52     STOP HARDWARE SYSTEM
00107A 5102 B6 EF52  A CHECK    LDAA   $EF52
00108A 5105 84 20    A          ANDA   #$20      CHECK BUFFER NOT EMPTY
00109A 5107 27 3A 5143          BEQ    DCENTR    ALL DATA IN, GET CNTR
00110A 5109 86 10    A          LDAA   #$10      ENABLE READ ENABLE
00111A 510B B7 EF52  A          STAA   $EF52
00112A 510E B6 EF40  A          LDAA   $EF40     GET WIDTH AND UNPACK
00113A 5111 16                  TAB              SAVE FOR FUTURE UNPACKING
00114A 5112 84 F0    A          ANDA   #$F0      MASK OTHER INFO
00115A 5114 44                  LSRA
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00116A 5115 44                       LSRA
00117A 5116 44                       LSRA
00118A 5117 81 03     A              CMPA     #3            MINIMUM WIDTH
00119A 5119 2F 23 513E               BLE      DISAB         IF TOO SMALL, SKIP
00120A 511B 7D 53D5   A              TST      COUNT2        FIRSTOGOODTWIDTH?
00121A 511E 26 1B 513B               BNE      JMP4          IF NOT, GO
00122A 5120 B6 EF42   A              LDAA     $EF42         FIRST GOOD LINE
00123A 5123 43                       COMA
00124A 5124 B7 535A   A MARK2        STAA     LDATA+1       STORE LSB OF RASTER LINE
00125A 5127 17                       TBA
00126A 5128 43                       COMA
00127A 5129 84 01     A              ANDA     #1
00128A 512B B7 5359   A              STAA     LDATA         STORE MSB OF RASTER LINE
00129A 512E B6 EF50   A              LDAA     $EF50         GET DISPLACEMENT DATA
00130A 5131 B7 5396   A MARK3        STAA     DDATA+1       STORE LSB OF DISPLACEMENT
00131A 5134 17                       TBA
00132A 5135 84 0E     A              ANDA     #$0E
00133A 5137 44                       LSRA
00134A 5138 B7 5395   A              STAA     DDATA
00135A 513B 7C 53D5   A JMP4         INC      COUNT2        COUNT # OF GOOD DOTS
00136A 513E 7F EF52   A DISAB        CLR      $EF52         DISABLE READ ENABLE
00137A 5141 20 BF 5102               BRA      CHECK
00138A 5143 B6 53D5   A DCENTR       LDAA     COUNT2        # OF LINES WITH A DOT
00139A 5146 B7 53DC   A              STAA     WDCNT
00140A 5149 FE 5359   A              LDX      LDATA         GET FIRST LINE #
00141A 514C FF 53D8   A              STX      LINE
00142A 514F FE 5395   A              LDX      DDATA         GET FIRST DISPLACEMENT
00143A 5152 FF 53DA   A              STX      MAX
00144A 5155 74 53DC   A              LSR      WDCNT         DIV BY TWO (FOR CENTER)
00145A 5158 B6 53D9   A              LDAA     LINE+1        D. P.  ADD FOR DOT CENTER
00146A 515B BB 53DC   A              ADDA     WDCNT         LSB ADD
00147A 515E B7 53D7   A              STAA     DOT+1         STORE LSB
00148A 5161 B6 53D8   A              LDAA     LINE
00149A 5164 89 00     A              ADCA     #0            MSB ADD
00150A 5166 B7 53D6   A              STAA     DOT           MSB STORE
00151A 5169 B6 53D7   A              LDAA     DOT+1
00152A 516C 84 01     A              ANDA     #1            TEST FOR ODD(NESS)
00153A 516E 27 01 5171               BEQ      ADD1          ADD ONE IF EVEN
00154A 5170 39                       RTS                    RETURN TO MAIN PROGRAM
00155A 5171 FE 53D6   A ADD1         LDX      DOT           ADD ONE TO MAKE ODD
00156A 5174 08                       INX
00157A 5175 FF 53D6   A              STX      DOT
00158A 5178 39                       RTS                    RETURN TO MAIN PROGRAM
00159A 5179 CE 00FF   A HUNT         LDX      #$FF
00160A 517C FF 53DF   A              STX      INFIN         MIRROR AT INFINITE DIST
00161A 517F CE FB54   A              LDX      #$FB54
00162A 5182 FF 53DD   A              STX      ZERO          MIRROR AT ZERO DISTANCE
00163A 5185 BD 50A2   A MZERO        JSR      COLECT        MOVE MIRROR TO ZERO
00164A 5188 FE 53D6   A              LDX      DOT           CHECK IF A DOT WAS SEEN
00165A 518B 26 72 51FF               BNE      JUMP          RETURN TO MAIN
00166A 518D B6 EF08   A              LDAA     $EF08
00167A 5190 01                       NOP
00168A 5191 FE EF08   A              LDX      $EF08         CHECK MIRROR POSITION
00169A 5194 FF 53E1   A              STX      LOCA          STORE MIRROR LOCATION
00170A 5197 B6 53E2   A              LDAA     LOCA+1        D. P.  SUBTR-DIFF TO ZERO
00171A 519A B0 53DE   A              SUBA     ZERO+1        LSB SUBTRACT
00172A 519D B7 53E4   A              STAA     DIFF+1        LSB RESULT STORE
00173A 51A0 B6 53E1   A              LDAA     LOCA
00174A 51A3 B2 53DD   A              SBCA     ZERO          MSB SUBTRACT
00175A 51A6 B7 53E3   A              STAA     DIFF          STORE MSB RESULT
00176A 51A9 FE 53E3   A              LDX      DIFF
00177A 51AC 2F 11 51BF               BLE      MINFIN        IF LT ZERO MOVE TO INFIN
00178A 51AE 7F EF70   A              CLR      $EF70         OTHERWISE MOVE TO ZERO
00179A 51B1 01                       NOP
00180A 51B2 01                       NOP
00181A 51B3 01                       NOP
00182A 51B4 01                       NOP
00183A 51B5 01                       NOP
00184A 51B6 01                       NOP
00185A 51B7 01                       NOP
00186A 51B8 86 88     A              LDAA     #$88
00187A 51BA B7 EF70   A              STAA     $EF70         MOVE MIRROR DOWN
00188A 51BD 20 C6 5185               BRA      MZERO
00189A 51BF BD 50A2   A MINFIN       JSR      COLECT        LOOK FOR DOT
00190A 51C2 FE 53D6   A              LDX      DOT           DOT THERE?
00191A 51C5 26 38 51FF               BNE      JUMP          IF DOT THERE, RETURN
00192A 51C7 B6 EF08   A              LDAA     $EF08
00193A 51CA 01                       NOP
00194A 51CB FE EF08   A              LDX      $EF08         GET MIRROR POSITION
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00195A 51CE FF 53E1  A          STX    LOCA      STORE MIRROR LOCATION
00196A 51D1 B6 53E2  A          LDAA   LOCA+1    D. P. SUBTR FOR DONE TEST
00197A 51D4 B0 53E0  A          SUBA   INFIN+1   LSB SUBTRACT
00198A 51D7 B7 53E4  A          STAA   DIFF+1    STORE LSB RESULT
00199A 51DA B6 53E1  A          LDAA   LOCA
00200A 51DD B2 53DF  A          SBCA   INFIN     MSB SUBTRACT
00201A 51E0 B7 53E3  A          STAA   DIFF      STORE MSB RESULT
00202A 51E3 FE 53E3  A          LDX    DIFF      CHECK IF DONE
00203A 51E6 2C 11 51F9          BGE    DIE       IF NO DOT, DIE
00204A 51E8 7F EF70  A          CLR    $EF70     MOVE MIRROR TO INFINITY
00205A 51EB 01                  NOP
00206A 51EC 01                  NOP
00207A 51ED 01                  NOP
00208A 51EE 01                  NOP
00209A 51EF 01                  NOP
00210A 51F0 01                  NOP
00211A 51F1 01                  NOP
00212A 51F2 86 A8    A          LDAA   #$A8
00213A 51F4 B7 EF70  A          STAA   $EF70     MOVE MIRROR
00214A 51F7 20 C6 51BF          BRA    MINFIN    RETURN AND LOOK FOR DOT
00215A 51F9 86 3F    A DIE      LDAA   #$3F
00216A 51FB B7 51FE  A          STAA   BK
00217A 51FE 01         BK       NOP
00218A 51FF 39         JUMP     RTS
00219                  ************************************************
00220                  *     MIRROR MOVE (ADJUST) SUBROUTINE          **
00221                  ************************************************
00222A 5200 B6 5001  A MOVE     LDAA   CONV+1    D. P. SUBTR FOR #L. O. C.
00223A 5203 B0 53D7  A          SUBA   DOT+1     L. O. C. =LINES OFF CENTER
00224A 5206 B7 53F4  A          STAA   LOC+1     STORE LSB RESULT
00225A 5209 B6 5000  A          LDAA   CONV
00226A 520C B2 53D6  A          SBCA   DOT       MSB SUBTRACT
00227A 520F B7 53F3  A          STAA   LOC       STORE MSB RESULT
00228A 5212 7F 53F5  A          CLR    MM        CLEAR MOTOR MOVEMENT VAR
00229A 5215 FE 53F3  A          LDX    LOC
00230A 5218 27 3F 5259          BEQ    GOBCK     NO MOVE IF CONVERGENT
00231A 521A 8C 01A0  A          CPX    #$1A0
00232A 521D 27 3A 5259          BEQ    GOBCK     SYSTEM ERROR FILTER
00233A 521F FE 53F3  A          LDX    LOC       GET LOC FOR BRANCH
00234A 5222 2B 1B 523F          BMI    MVUP      IF LOC NEG, MOVE DOT UP
00235A 5224 86 20    A MVDN     LDAA   #$20
00236A 5226 B7 53F5  A          STAA   MM
00237A 5229 BD 53FE  A          JSR    CLCMV
00238A 522C 7F EF70  A          CLR    $EF70
00239A 522F 01                  NOP
00240A 5230 01                  NOP
00241A 5231 01                  NOP
00242A 5232 01                  NOP
00243A 5233 01                  NOP
00244A 5234 01                  NOP
00245A 5235 01                  NOP
00246A 5236 B6 53F5  A          LDAA   MM        GET MOTOR MOVEMENT
00247A 5239 B7 EF70  A          STAA   $EF70
00248A 523C 7E 5259  A          JMP    GOBCK     RETURN TO MAIN PROG
00249A 523F B6 53F4  A MVUP     LDAA   LOC+1
00250A 5242 40                  NEGA
00251A 5243 B7 53F4  A          STAA   LOC+1     ABSOLUTE VALUE OF LOC
00252A 5246 BD 53FE  A          JSR    CLCMV
00253A 5249 7F EF70  A          CLR    $EF70
00254A 524C 01                  NOP
00255A 524D 01                  NOP
00256A 524E 01                  NOP
00257A 524F 01                  NOP
00258A 5250 01                  NOP
00259A 5251 01                  NOP
00260A 5252 01                  NOP
00261A 5253 B6 53F5  A          LDAA   MM        GET MOTOR MOVEMENT
00262A 5256 B7 EF70  A          STAA   $EF70     STORE IN MOTOR PIA
00263A 5259 39         GOBCK    RTS
00264A 525A B6 EF08  A DIST     LDAA   $EF08
00265A 525D 01                  NOP
00266A 525E FE EF08  A          LDX    $EF08     GET MIRROR VOLTAGE
00267A 5261 FF 53EF  A          STX    MIRAD     STORE IN MIRROR A/D
00268A 5264 B6 53F0  A          LDAA   MIRAD+1   D. P. ADD- MIRROR A/D PLUS
00269A 5267 8B FF    A          ADDA   #$FF      $3FF (BIAS FOR TABLE)
00270A 5269 B7 53F2  A          STAA   TOFSET+1  STORE LSB IN TABLE OFFSET
00271A 526C B6 53EF  A          LDAA   MIRAD
00272A 526F 89 03    A          ADCA   #3        MSB ADD
00273A 5271 B7 53F1  A          STAA   TOFSET    STORE MSB IN TABLE OFFSET
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00274A 5274 B6 53F2   A          LDAA   TOFSET+1 MULTATABLEFOFFSETYBYWTWO
00275A 5277 BB 53F2   A          ADDA   TOFSET+1 FOR D. P.  DATA
00276A 527A B7 53F2   A          STAA   TOFSET+1 STORE LSB
00277A 527D B6 53F1   A          LDAA   TOFSET
00278A 5280 B9 53F1   A          ADCA   TOFSET   ADD MSB
00279A 5283 B7 53F1   A          STAA   TOFSET   STORE MSB
00280A 5286 B6 53F1   A          LDAA   TOFSET   ADD IN TABLE INITIALIZE
00281A 5289 8B 75     A          ADDA   #$75     LOCATE TABLE AT $7000
00282A 528B B7 53F1   A          STAA   TOFSET   STORE IN MSB
00283A 528E FE 53F1   A          LDX    TOFSET   GET TABLE OFFSET
00284A 5291 FF 5295   A          STX    FLAG1+1  INJECT IN DATA RETR  LOCA
00285A 5294 FE 7000   A FLAG1    LDX    $7000    GET OUTPUT DATA FROM TABLE
00286A 5297 FF 53F6   A          STX    TEMP2    STORE TO DO BIAS $ SCALE
00287A 529A FF 53E9   A          STX    ER1      STORE FOR ERROR CALC
00288A 529D B6 53F7   A          LDAA   TEMP2+1  ADD LSB BIAS FACTOR
00289A 52A0 BB 5006   A          ADDA   BIAS+1   LSB ADD
00290A 52A3 B7 53F7   A          STAA   TEMP2+1  STORE BIASED LSB
00291A 52A6 B6 53F6   A          LDAA   TEMP2
00292A 52A9 B9 5005   A          ADCA   BIAS     ADD MSB BIAS FACTOR
00293A 52AC B7 53F6   A          STAA   TEMP2    STORE BIASED MSB
00294                   * MULTIPLY BY 1. 5 TO APPROX SCALE OUTPUT**
00295A 52AF B6 53F6   A          LDAA   TEMP2    GET MSB OF VOLTAGE
00296A 52B2 44                   LSRA            DIVIDE BY 2
00297A 52B3 B7 53F8   A          STAA   TEMP3    STORE MSB QUOTIENT
00298A 52B6 B6 53F7   A          LDAA   TEMP2+1  GET LSB OF VOLTAGE
00299A 52B9 46                   RORA            DIVIDE BY 2 (PULL CARRY IN)
00300A 52BA B7 53F9   A          STAA   TEMP3+1  STORE LSB QUOTIENT
00301A 52BD B6 53F7   A          LDAA   TEMP2+1  ADD FOR 1 5 SCALE FACTOR
00302A 52C0 BB 53F9   A          ADDA   TEMP3+1  LSB ADD
00303A 52C3 B7 53FB   A          STAA   INSOUT+1 STORE LSB OF ALTIM OUTPUT
00304A 52C6 B6 53F8   A          LDAA   TEMP3
00305A 52C9 B9 53F6   A          ADCA   TEMP2    MSB ADD
00306A 52CC B7 53FA   A          STAA   INSOUT   STORE MSB OF ALTIM OUTPUT
00307A 52CF FE 53FA   A          LDX    INSOUT   GET BIASED AND SCALED VALUE
00308A 52D2 FF EF20   A          STX    $EF20    DO D/A CONV FOR ALTIM OUTPUT
00309A 52D5 FE 53E9   A          LDX    ER1      GET ORIG TABLE VALUE
00310A 52D8 FF EF24   A          STX    $EF24    DO D/A FOR STRIP CHART
00311A 52DB B6 EF0C   A          LDAA   $EF0C
00312A 52DE 01                   NOP
00313A 52DF FE EF0C   A          LDX    $EF0C    GET TRACK VOLTAGE
00314A 52E2 FF 53EB   A          STX    ER2      STORE FOR ERROR CALC
00315A 52E5 B6 53EA   A          LDAA   ER1+1    D. P.  SUBTR FOR ERROR CALC
00316A 52E8 B0 53EC   A          SUBA   ER2+1    LSB SUBTR
00317A 52EB B7 53EE   A          STAA   ERROR+1  LSB ERROR
00318A 52EE B6 53E9   A          LDAA   ER1
00319A 52F1 B2 53EB   A          SBCA   ER2      MSB SUBTRACT
00320A 52F4 B7 53ED   A          STAA   ERROR    MSB ERROR
00321A 52F7 FE 53ED   A          LDX    ERROR    GET FINAL ERROR VALUE
00322A 52FA FF EF22   A          STX    $EF22    DO D/A FOR STRIP CHART
00323A 52FD 39                   RTS
00324A 52FE B6 53F4   A CLCMV    LDAA   LOC+1
00325A 5301 B1 5002   A          CMPA   SMMV     MAKE A SMALL MOV'T?
00326A 5304 2D 27 532D           BLT    SMALL
00327A 5306 B1 5003   A          CMPA   MDMV     MAKE A MEDIUM MOV'T?
00328A 5309 2D 18 5323           BLT    MED
00329A 530B B1 5004   A          CMPA   LGMV     MAKE A LARGE MOV'T?
00330A 530E 2D 0A 531A           BLT    LARGE
00331A 5310 86 84     A LGST     LDAA   #$84     LARGEST POSS MOV'T
00332A 5312 F6 53F5   A          LDAB   MM       GET DIRECTION
00333A 5315 1B                   ABA             COMBINE
00334A 5316 B7 53F5   A          STAA   MM       STORE COMPLETED MOV'T
00335A 5319 39                   RTS
00336A 531A 86 83     A LARGE    LDAA   #$83     LARGE MOV'T
00337A 531C F6 53F5   A          LDAB   MM       GET DIRECTION
00338A 531F 1B                   ABA             COMBINE
00339A 5320 B7 53F5   A          STAA   MM       STORE COMPLETED MM
00340A 5323 86 82     A MED      LDAA   #$82     MEDIUM MOV'T
00341A 5325 F6 53F5   A          LDAB   MM       GET DIRECTION
00342A 5328 1B                   ABA             COMBINE
00343A 5329 B7 53F5   A          STAA   MM       STORE MOTOR MOV'T
00344A 532C 39                   RTS
00345A 532D 86 81     A SMALL    LDAA   #$81     SMALLEST POSS MOV'T
00346A 532F F6 53F5   A          LDAB   MM       GET DIRECTION
00347A 5332 1B                   ABA             COMBINE
00348A 5333 B7 53F5   A          STAA   MM       STORE MOV'T
00349A 5336 39                   RTS
00350A 5337      0002 A VARI     RMB    2
00351A 5339      0001 A STB1     RMB    1        # OF NO DOT PASSES
00352A 533A      0001 A STABLE   RMB    1        # OF LINE STABLE PASSES
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03530 00353A 533B     001E  A WDATA   RMB     30          WIDTH OF DOT DATA
03540 00354A 5359     003C  A LDATA   RMB     60          RASTER LINE # DATA
03550 00355A 5395     003C  A DDATA   RMB     60          DISPLACEMENT DATA
03560 00356A 53D1     0001  A COUNT1  RMB     1           # OF COLLECT PASSES
03570 00357A 53D2     0001  A NUMB1   RMB     1
03580 00358A 53D3     0002  A DUMMY   RMB     2           DUMMY TIME PAD VAR.
03590 00359A 53D5     0001  A COUNT2  RMB     1           # OF LINES WITH A GOOD DOT
03600 00360A 53D6     0002  A DOT     RMB     2           LOCATION OF DOT CENTER
03610 00361A 53D8     0002  A LINE    RMB     2           TEMP STORE FOR DOT CENTER
03620 00362A 53DA     0002  A MAX     RMB     2           SAME AS ABOVE .
03630 00363A 53DC     0001  A WDCNT   RMB     1           # OF LINES W/ A GOOD DOT
03640 00364A 53DD     0002  A ZERO    RMB     2           MIRROR VOLTAGE @ DIST=0
03650 00365A 53DF     0002  A INFIN   RMB     2           MIRROR VOLTAGE @ D=INFIN
03660 00366A 53E1     0002  A LOCA    RMB     2           CURRENT VOLTAGE OF MIRROR
03670 00367A 53E3     0002  A DIFF    RMB     2           DIFF BETW LOCA AND GOAL
03680 00368A 53E5     0002  A TEMP1   RMB     2           TEMP REG FOR MOV'T CALC
03690 00369A 53E7     0002  A TADD    RMB     2           TABLE ADDRESS
03700 00370A 53E9     0002  A ER1     RMB     2           SYSTEM ERROR VAR 1
03710 00371A 53EB     0002  A ER2     RMB     2           SYSTEM ERROR VAR 2
03720 00372A 53ED     0002  A ERROR   RMB     2           RESULTANT SYSTEM ERROR
03730 00373A 53EF     0002  A MIRAD   RMB     2           MIRROR VOLTAGE FOR DIST
03740 00374A 53F1     0002  A TOFSET  RMB     2           TABLE OFFSET (BIAS)
03750 00375A 53F3     0002  A LOC     RMB     2           # OF LINES OFF CONVERGE
03760 00376A 53F5     0001  A MM      RMB     1           MOTOR MOVEMENT
03770 00377A 53F6     0002  A TEMP2   RMB     2           TEMP REG FOR DIST CALC
03780 00378A 53F8     0002  A TEMP3   RMB     2           TEMP REG FOR DIST CALC
03790 00379A 53FA     0002  A INSOUT  RMB     2           ALTIMETER OUTPUT VOLTAGE
03800 00380A 53FC 39          RETU    RTS
03810 00381                           END
TOTAL ERRORS 00000--00000
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   5171 ADD1     00153 00155*
   5005 BIAS     00013*00289 00292

51FE BK      00216 00217*
5102 CHECK   00107*00137
52FE CLCMV   00237 00252 00324*
50A2 COLECT  00045 00073*00163 00189
5000 CONV    00009*00061 00222 00225
53D1 COUNT1  00077 00100 00101 00356*
53D5 COUNT2  00079 00120 00135 00138 00359*
5143 DCENTR  00109 00138*
5395 DDATA   00075 00076 00130 00134 00142 00355*
51F9 DIE     00203 00215*
53E3 DIFF    00172 00175 00176 00198 00201 00202 00367*
513E DISAB   00119 00136*
525A DIST    00046 00069 00264*
53D6 DOT     00047 00104 00147 00150 00151 00155 00157 00164 00190 00223 00226 00360*
509D DRIVE   00065 00071*
53D3 DUMMY   00086 00087 00088 00089 00090 00091 00092 00093 00094 00095 00096 00097
             00098 00099 00358*
53E9 ER1     00287 00309 00315 00318 00370*
53EB ER2     00314 00316 00319 00371*
53ED ERROR   00317 00320 00321 00372*
5069 FILTER  00050*
5037 FLAG    00031*00037
5294 FLAG1   00284 00285*
505B GO      00045*00051 00057 00060 00067 00070 00072
5259 GOBCK   00230 00232 00248 00263*
5179 HUNT    00059 00159*
53DF INFIN   00160 00197 00200 00365*
53FA INSOUT  00303 00306 00307 00379*
50C1 JMP2    00084*00102
513B JMP4    00121 00135*
51FF JUMP    00165 00191 00218*
531A LARGE   00330 00336*
5359 LDATA   00073 00074 00124 00128 00140 00354*
5004 LGMV    00012*00329
5310 LGST    00331*
53D8 LINE    00141 00145 00148 00361*
53F3 LOC     00224 00227 00229 00233 00249 00251 00324 00375*
53E1 LOCA    00169 00170 00173 00195 00196 00199 00366*
5124 MARK2   00124*
5131 MARK3   00130*
53DA MAX     00143 00362*
5003 MDMV    00011*00327
5323 MED     00328 00340*
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51BF MINFIN 00177 00189*00214
53EF MIRAD  00267 00268 00271 00373*
53F5 MM     00228 00236 00246 00261 00332 00334 00337 00339 00341 00343 00346 00348
            00376*
5200 MOVE   00071 00222*
5224 MVDN   00235*
523F MVUP   00234 00249*
5185 MZERO  00163*00188
53D2 NUMB1  00078 00357*
5048 OUTLOP 00033 00038*
50FF READ   00085 00106*
53FC RETU   00380*
5084 RUN    00052 00061*
507C SEND   00055 00058*
5095 SET1   00062 00068*
532D SMALL  00326 00345*
5002 SMMV   00010*00325
5070 STA1   00048 00053*
533A STABLE 00038 00064 00066 00068 00352*
5339 STB1   00039 00049 00054 00056 00058 00351*
53E7 TADD   00369*
53E5 TEMP1  00368*
53F6 TEMP2  00286 00288 00290 00291 00293 00295 00298 00301 00305 00377*
53F8 TEMP3  00297 00300 00302 00304 00378*
53F1 TOFSET 00270 00273 00274 00275 00276 00277 00278 00279 00280 00282 00283 00374*
5337 VARI   00350*
533B WDATA  00353*
53DC WDCNT  00139 00144 00146 00363*
53DD ZERO   00162 00171 00174 00364*
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I claim:

1. In a method for determining the altitude of a flight simulator probe moving relative to and above the terrain of a flight simulator model wherein the imaginary line extending from the probe in a direction normal to the model is characterized as the probe plumb line, the steps of:

directing a pencil-like beam of radiation from said probe onto the model keeping said beam within a plane containing said probe plumb line to produce a beam spot on said model;

detecting the location of said beam spot relative to two orthogonal coordinates with a detector situated remote from said probe plumb line and having a linear sensitivity zone optically aligned with said probe plumb line;

varying the angular orientation of the beam within said probe plumb line plane and relative to a reference plane so as to cause said beam spot to impinge on the model site intersected by said probe plumb line;

determining the angular orientation of the beam relative to said reference plane; and

utilizing the determined angular orientation of said beam to determine the altitude of said probe over the terrain of the model.

2. The method of claim 1 including the step of, directing a second beam of radiation onto the terrain of the model from a position on the probe angularly spaced from the position of the first beam taken about an axis of revolution generally coaxially of said probe plumb line; and detecting the second beam spot when said first beam spot is obstructed by the terrain from reaching the intersection of the model and the probe plumb line.

3. The method of claim 1 wherein said beam of radiation is a beam of monochromatic, collimated light.

4. The method of claim 1 wherein the step of detecting the beam spot includes the step of directing a beam spot image through a light pipe on a path between the beam spot and the detector.

5. The method of claim 2 wherein the step of directing the second beam of radiation onto the terrain includes the step of splitting off of the first beam a portion of its energy to produce said second beam.

6. In a flight simulator apparatus of the type where a probe simulates an aircraft and the simulator operator controls the motion of the probe relative to the terrain of a model while viewing said model via a video monitor on said probe:

means for directing a pencil-like beam of radiation from the probe onto the terrain of the model to produce a beam spot on the model where the beam impinges on the model, an imaginary line extending from said probe normal to said model being known as the probe plumb line;

means supported by said probe for detecting the location of said beam impingement on said model, said means being remote from said probe plumb line, being two-dimensionally sensitive, and having a linear sensitivity zone in optical alignment with said probe plumb line;

servo means coupled to said beam directing means and said detecting means for varying the angular direction of the beam in a plane containing the probe plumb line and maintaining the beam spot on the model at the site where the probe plumb line intersects the model;

means for determining the angular orientation of the beam relative to a reference plane; and

means for utilizing the determined angular orientation of said beam to determine the distance between said probe and said model measured along said probe plumb line.

7. The apparatus of claim 6 including:

means for directing a second beam of radiation onto the terrain of the model from a position on the probe angularly spaced from the position of the first beam taken about an axis of revolution generally coaxial of said probe plumb line; and

means for detecting the second beam spot when said first beam spot is obstructed by the terrain from

reaching the model site intersected by the probe plumb line.

8. The apparatus of claim 6 wherein said means for directing a pencil-like beam of radiation includes means for directing a pencil-like beam of monochromatic, collimated light.

9. The apparatus of claim 6 including light pipe means for directing an image of said beam spot to said detecting means.

10. The apparatus of claim 7 including beam splitter means for splitting off a portion of said first beam to produce said second beam.

11. The apparatus of claim 6 wherein said detecting means includes a video camera.

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